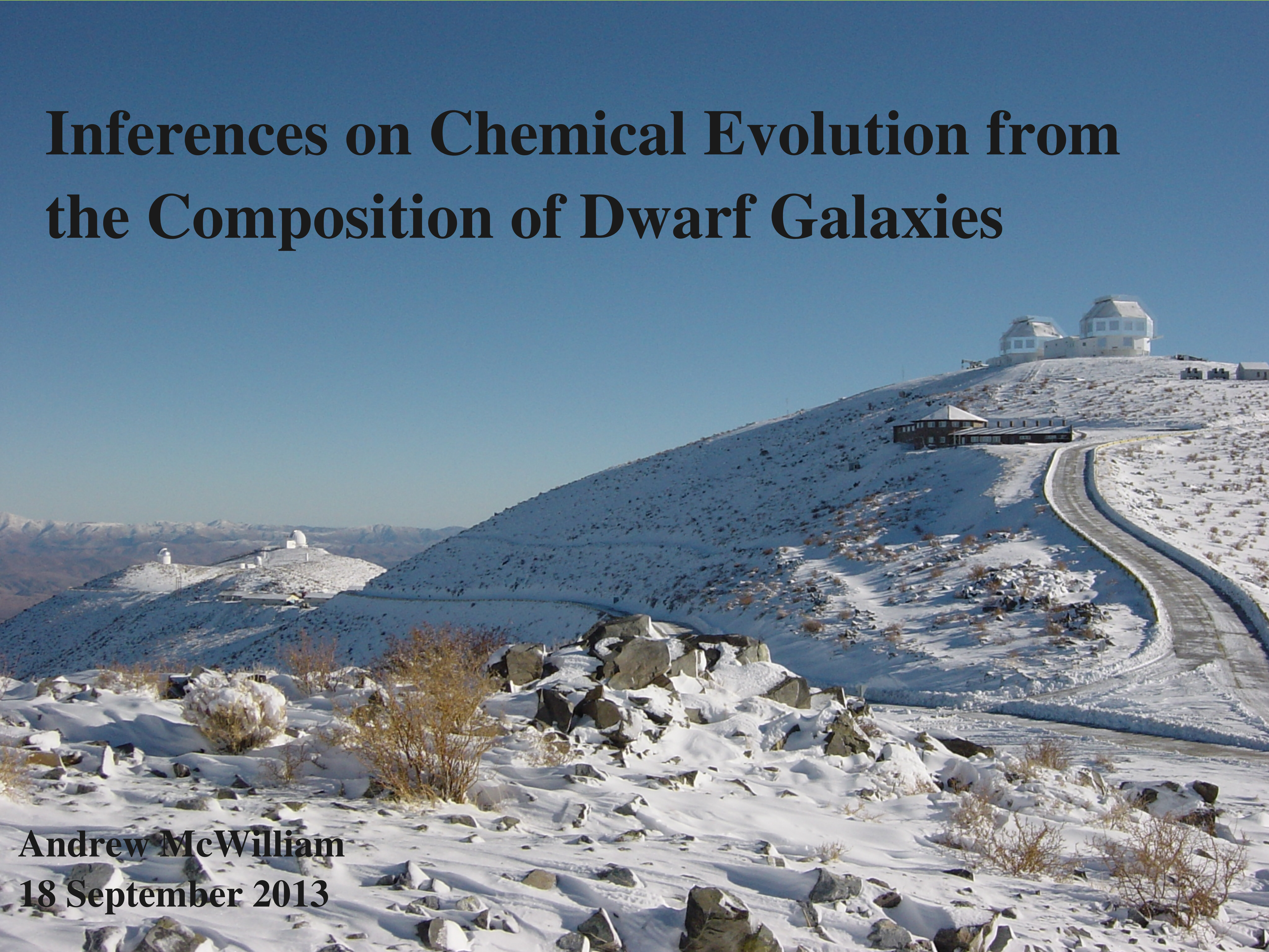
Inferences on Chemical Evolution from the Composition of Dwarf Galaxies



Andrew McWilliam

18 September 2013

Matteucci & Brocato (1990) predictions

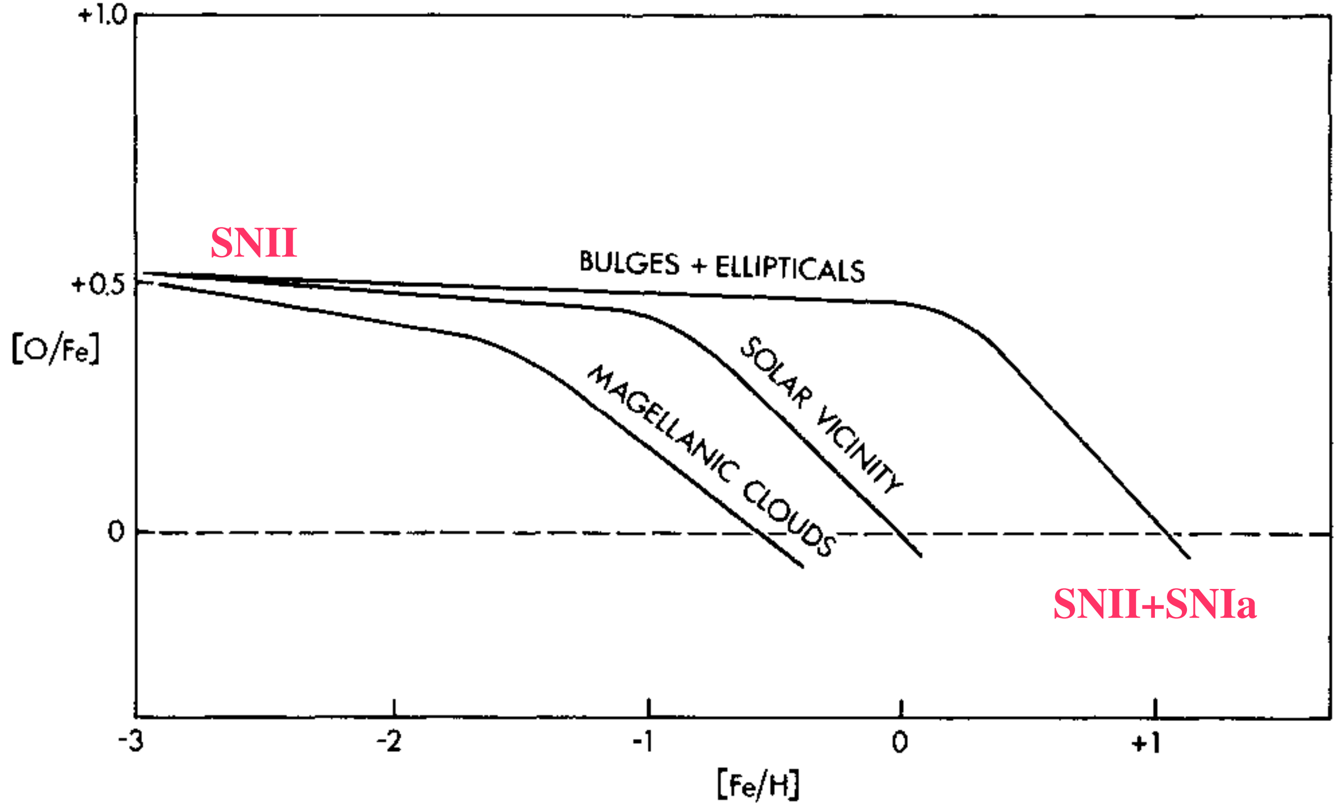


FIG. 4.—A sketch of the predicted [O/Fe] vs. [Fe/H] relations in different systems as a consequence of their different [Fe/H]-*t* relations.

time-delay

Star-formation rate determines [Fe/H] of the knee

Chemical abundance analysis of 3 RGB stars in the Sagittarius dwarf galaxy (Sgr)

- **Differential, line by line, relative to Arcturus (reduces errors), LTE model atmosphere analysis.**

- **Compare to results from Bonifacio et al. (2000, 2004), Smecker-Hane & McWilliam (2002), Sbordone et al. (2007), and Carretta et al. (2010).**

- **Motivation: the chemistry of different environments (e.g. Bulge, disk, halo, GCs, galaxies of all types) can test our ideas of chemical evolution and galaxy evolution.**

See arXiv:1309.2974 for many more results than discussed here

Main Conclusions:

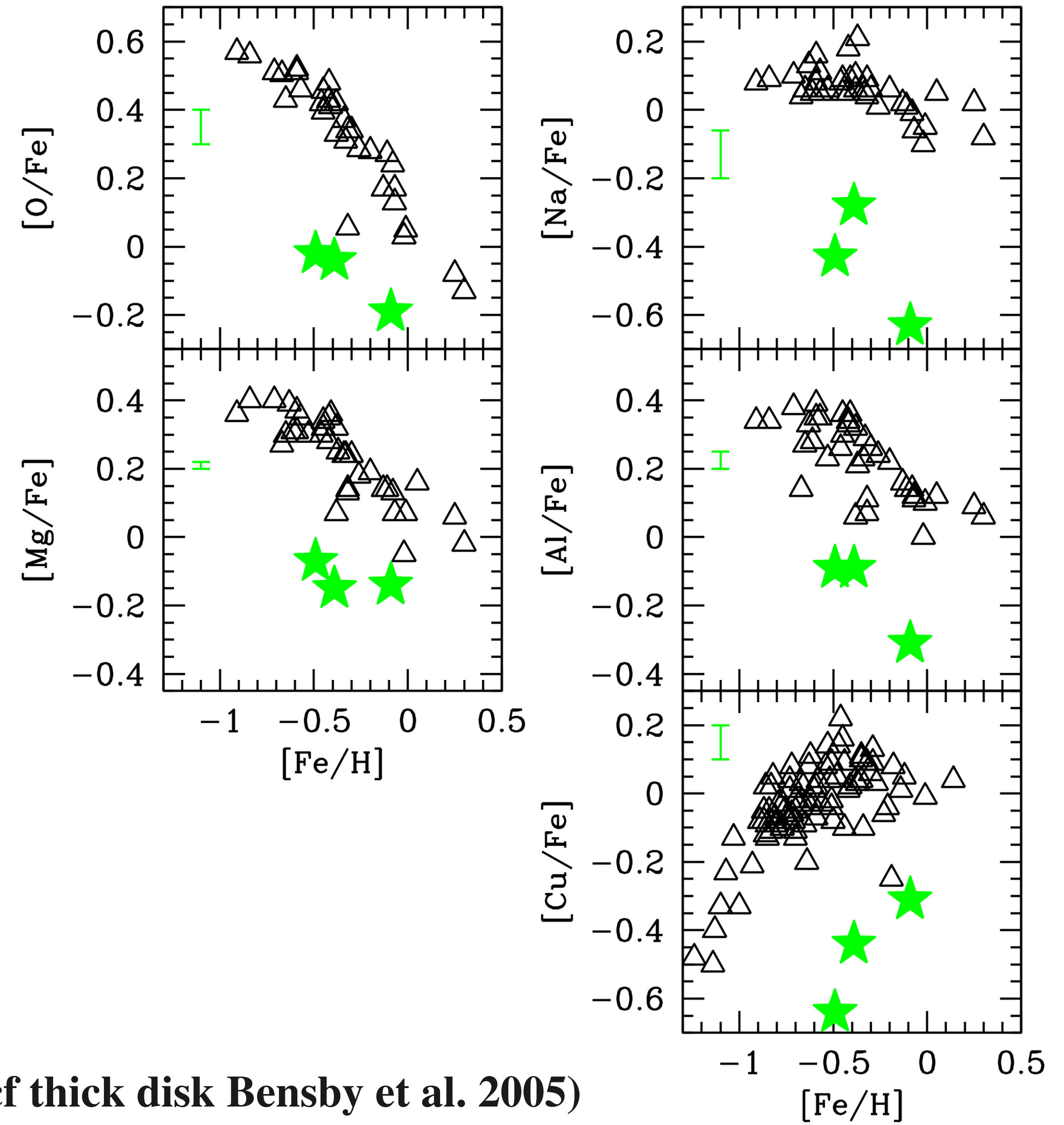
- **Sgr [alpha/Fe] deficiencies result from an IMF missing the most massive stars, not from delayed SNIa iron** (cf Weidner & Kroupa 2005)**.**
- **Other dwarf galaxies (Fornax, IC1613, and the LMC) show similar [Eu/O] ratios, also indicating a top-light IMF or steep IMF slope.**
- **The r-process is associated with lower-mass SNII.**
- **The [Eu/Fe] trend with [Fe/H] is similar, or identical, in the MW bulge, disk and Sgr; this is a challenge for the SNIa time delay scenario.**

Sgr <u>hydrostatic</u> [X/Fe] compared to MW thick disk

0.43+/-0.04 dex deficiency

Table 1. Sgr–Thick Disk Element Differences

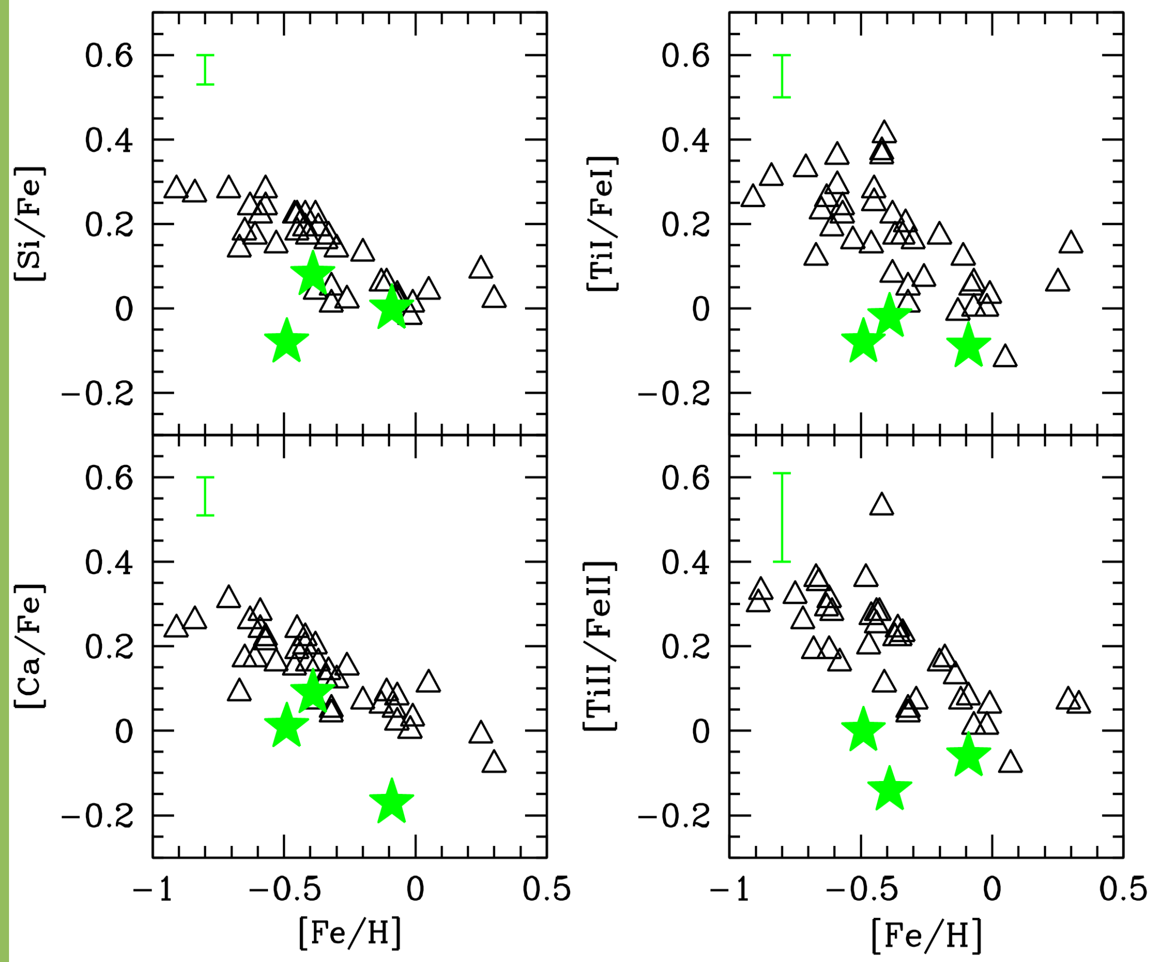
Species	Δ[X/Fe] (dex)	Δ Fe (dex)
[O I]	−0.43 ± 0.03	−0.7
Na I	−0.50 ± 0.09	−0.5
Mg I	−0.34 ± 0.05	−0.5
Al I	−0.39 ± 0.04	−0.5
Si I	−0.14 ± 0.06	−0.2
Ca I	−0.16 ± 0.05	−0.2
Ti I	−0.20 ± 0.07	−0.35
Ti II	−0.21 ± 0.08	−0.35
Cu I	−0.50 ± 0.11	−0.4



(cf thick disk Bensby et al. 2005)

Sgr **explosive** [X/Fe] compared to MW thick disk

0.17+/-0.03 dex deficiency

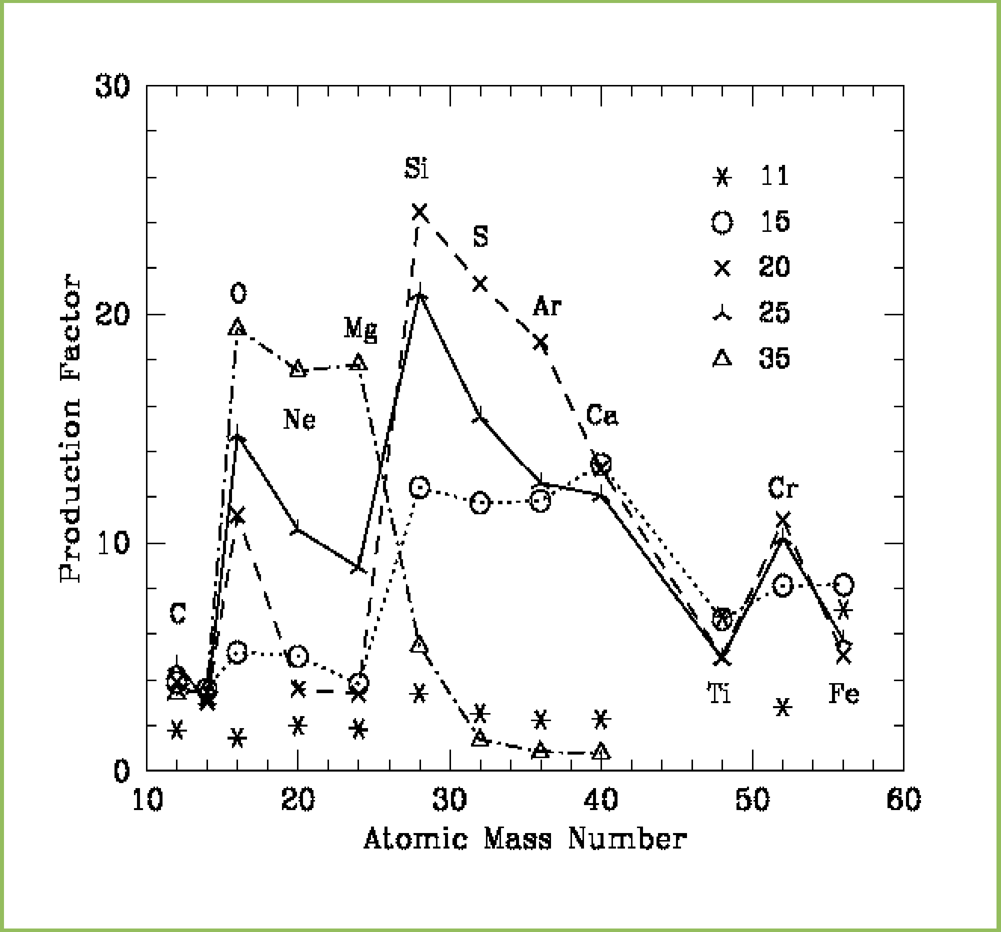


(cf Bensby et al. 2005)

• A low hydrostatic/explosive ratio can occur if there is a deficit of high mass SNII progenitors → sensitive to IMF slope

Different alpha-elements made by different mass SNII

O-Mg >25 Msun
Si-Ca 15-25 Msun



WW95

- O, Mg, Na, Al, Cu
  hydrostatic burning
- Yield increases with mass.
- Si-Ca made explosively. Fallback
  reduces yield at high mass.
- Si,Ca,Ti uncertain SNIa yields
  (e.g. Maeder et al. 2010)

top-light Sgr IMF?

Eu behaves like an alpha-element in the Solar neighborhood

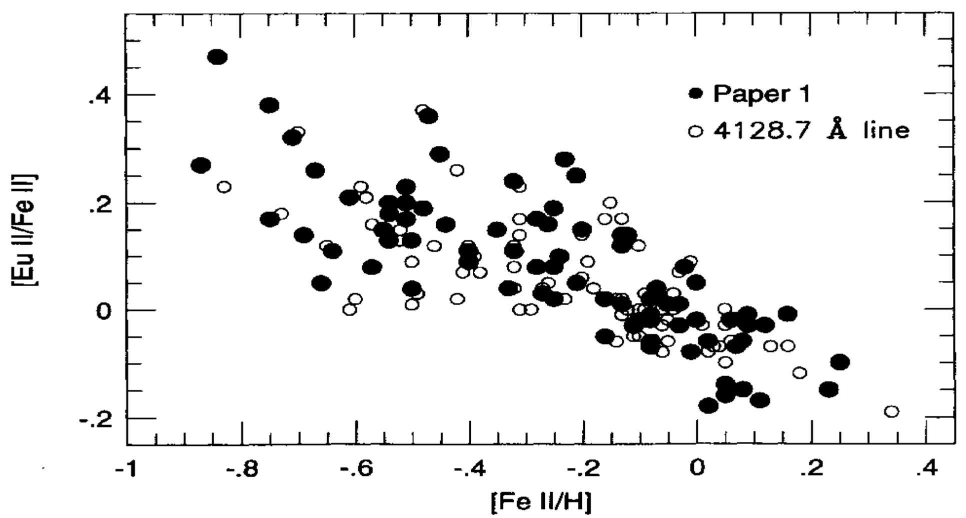


FIG. 5.—*Top panel*: [Fe II/H] from Paper I compared to that from the 4128.7 Å line. *Bottom panel*: [Eu II/Fe II] vs. [Fe II/H] with Fe II as indicated.

Woolf & Lambert (1995)

(but see McWilliam & Rich 1994)

Suggests a SNII origin

Eu is ~95% r-process

R-Process [Eu/Fe]r trend*

– same as MW thick disk

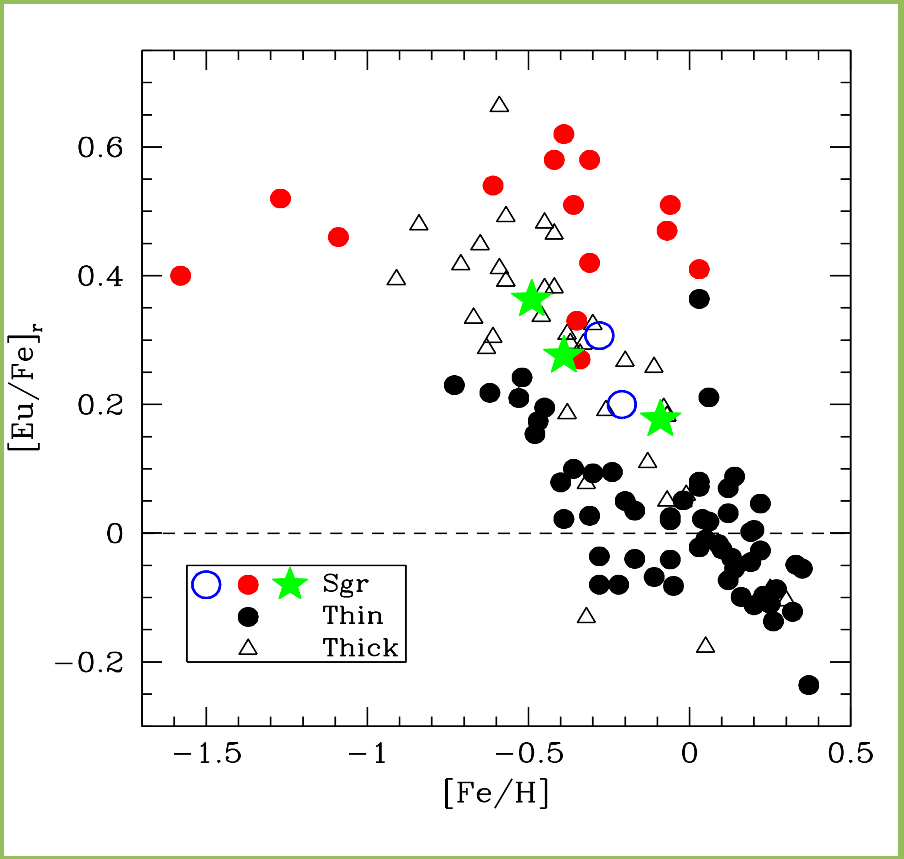
(* corrected for s- fraction)

But [O/Fe] is deficient !

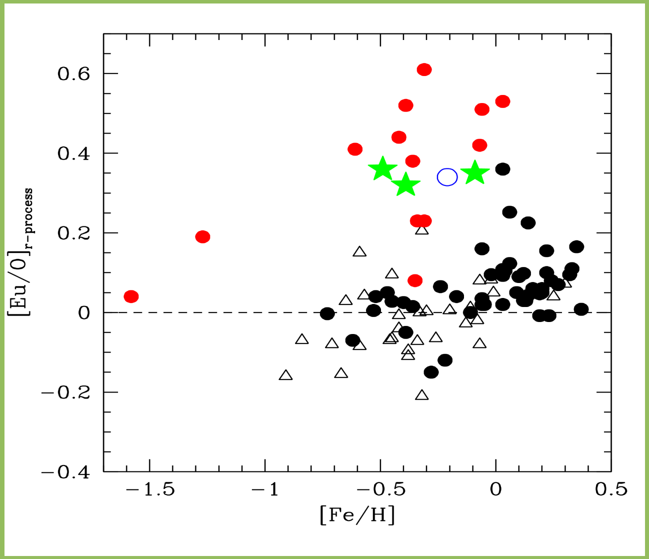
[O/Fe] and [Eu/Fe] require two processes

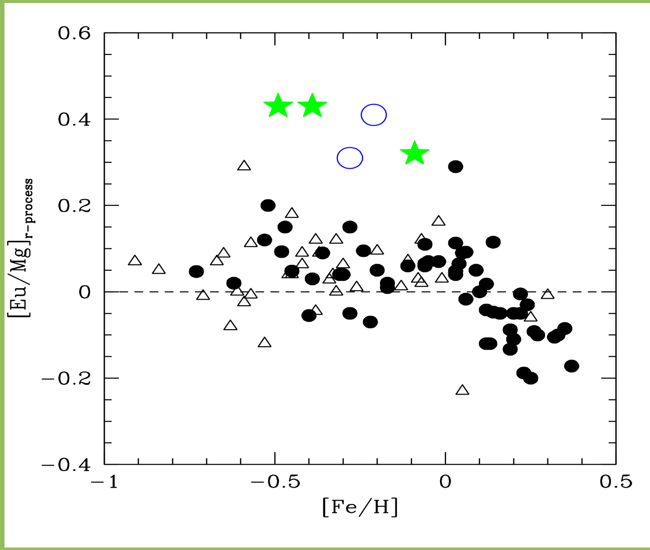
(can't explain both with SNIa iron)

N.B. SM02 enhanced Eu: I thought it was s-process Eu



(cf MW disk: Bensby et al. 2005)





[Eu/O]r and [Eu/Mg]r ~+0.4 dex

HOW CAN THIS BE?

Two reasonable scenarios to explain enhanced [Eu/O]r:

1. [O/Fe] low due to top-light IMF, while [Eu/Fe]r decline due to SNIa iron.
   → Suggests a similar SFR for MW thick disk and Sgr.

2. [O/Fe] due to top-light IMF, metallicity-dependent [Eu/Fe]r yield, while delayed SNIa iron had **no** significant effect.

Weidner & Kroupa (2005), Kroupa (2011): dwarf galaxies should have a top-light IMF, due to a paucity of the most massive molecular clouds.

Note: metal-dependent SNIa r-process origin is difficult to contrive and requires an additional mechanism.

Conclusion 1:

The low [alpha/Fe] ratios in Sgr are due to a top-light IMF (or steep IMF slope), not the delayed addition of Fe from SNIa.

[Eu/O]r depends on the IMF.

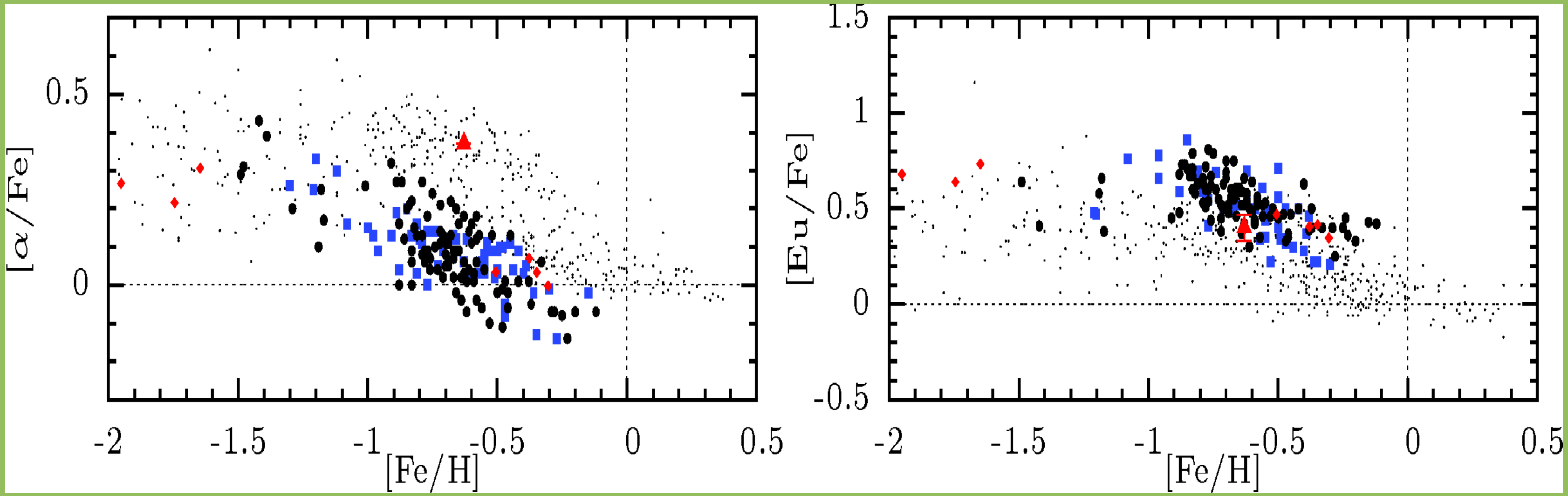
Conclusion 2:

The r-process is associated with lower-mass SNII

Enhanced [Eu/O]r can occur with an IMF deficient in high-mass SNII

- **<u>Similar [Eu/O] enhancements are seen in other dwarf galaxies:</u>**

LMC has low alpha, high [Eu/Fe] (e.g. van der Swaelmen et al. 2013)



Also: Fornax (Letarte et al. 2010, 2013)
IC 1613 (Tautvaisiene et al. 2007)

Conclusion 3:

[alpha/Fe] deficiencies due to top-light (or steep slope) IMF are common in dwarf galaxies.

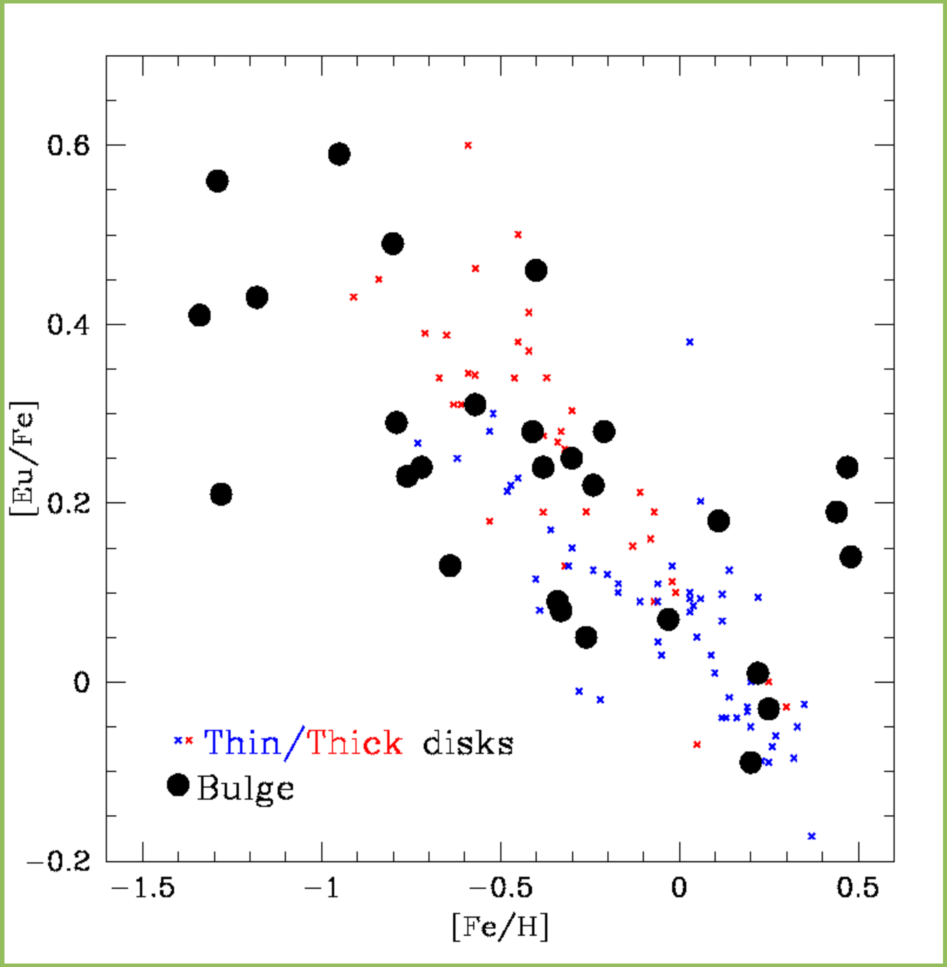
Note: Tolstoy et al. (2003) claimed top-light IMF for 4 dSphs, based on hydrostatic/explosive alpha-element ratios.

However, the same group (Venn et al. 2004) abandoned this claim due to the possibility of explosive alphas from enhanced SNIa nucleosynthesis.

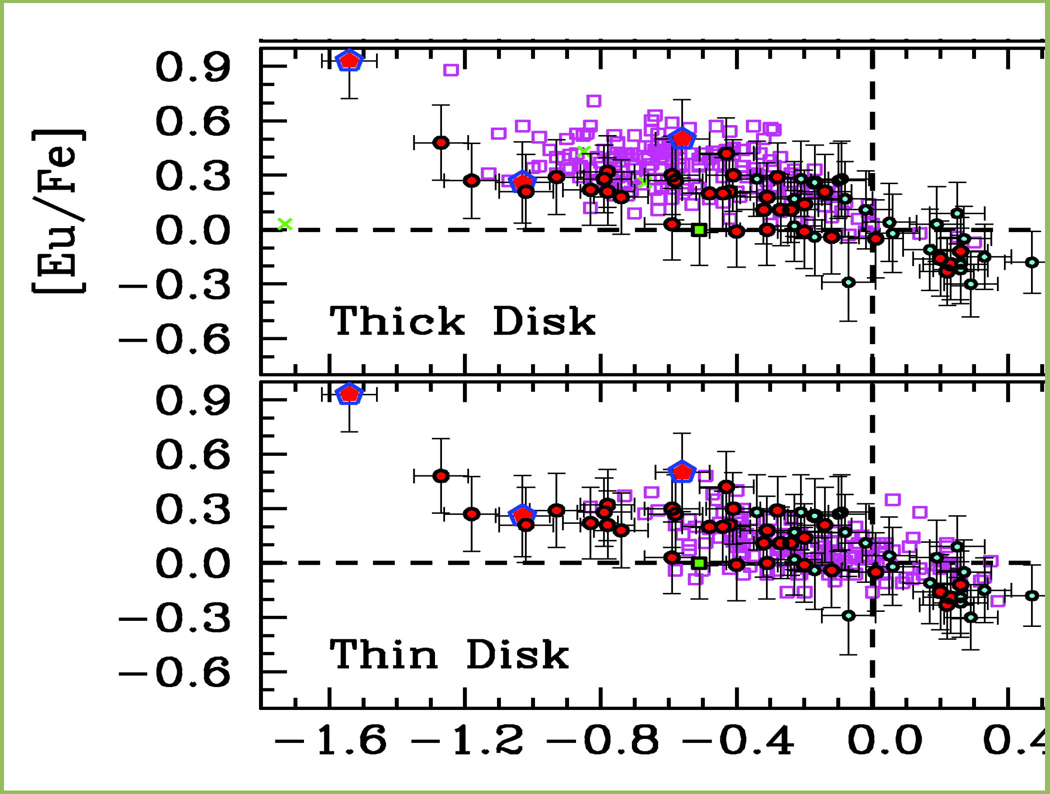
Concern #1:

The [Eu/Fe] trend is similar in the MW bulge, disk, and Sgr, (and LMC?), despite their putative different formation timescales.

Normal [Eu/Fe] in the MW bulge



Fulbright (McWilliam et al. 2010)



[Fe/H]

Johnson et al. (2012)

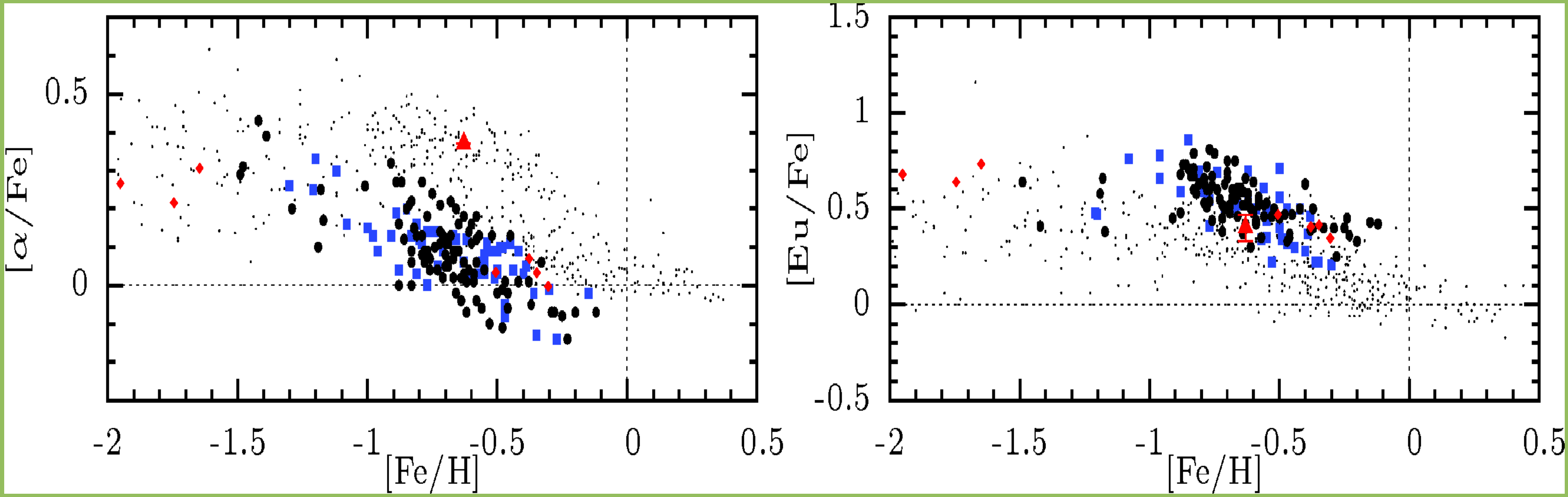
How can this be?

Isochrone fits to cmds (Zoccali et al. 2003; Clarkson et al. 2008) and low [La/Eu] ratios (Fulbright/McWilliam et al. 2010; Johnson et al. 2012)

→ **high SFR and rapid formation timescale for the bulge.**

<u>LMC</u>

Van der Swaelemen et al. LMC zero-point problem?



Concern #2

Radial abundance gradients in the MW disk (Yong et al. 2012) show the same [alpha/Fe] trend with [Fe/H], independent of Galactocentric radius, despite the expected lower SFR in the outer disk.

- Depends on expected SFR differences at the observed Galactic radius

The nearly identical [Eu/Fe] trend of Sgr and the MW disk and bulge (and possibly LMC) contradicts expectations of the SNIa time-delay scenario.

If correct, it would be necessary to explain the [alpha/Fe] trend in the MW by alternate means, or with help from effects such as stellar winds, or IMF modulation.

→ **More Sgr Eu abundances (and other elements) are required**

Main Conclusions:

- **Sgr [alpha/Fe] deficiencies result from an IMF missing the most massive stars, not from delayed SNIa iron** (cf Weidner & Kroupa 2005)**.**
- **Other dwarf galaxies (Fornax, IC1613, and the LMC) show similar [Eu/O] ratios, also indicating a top-light IMF or steep IMF slope.**
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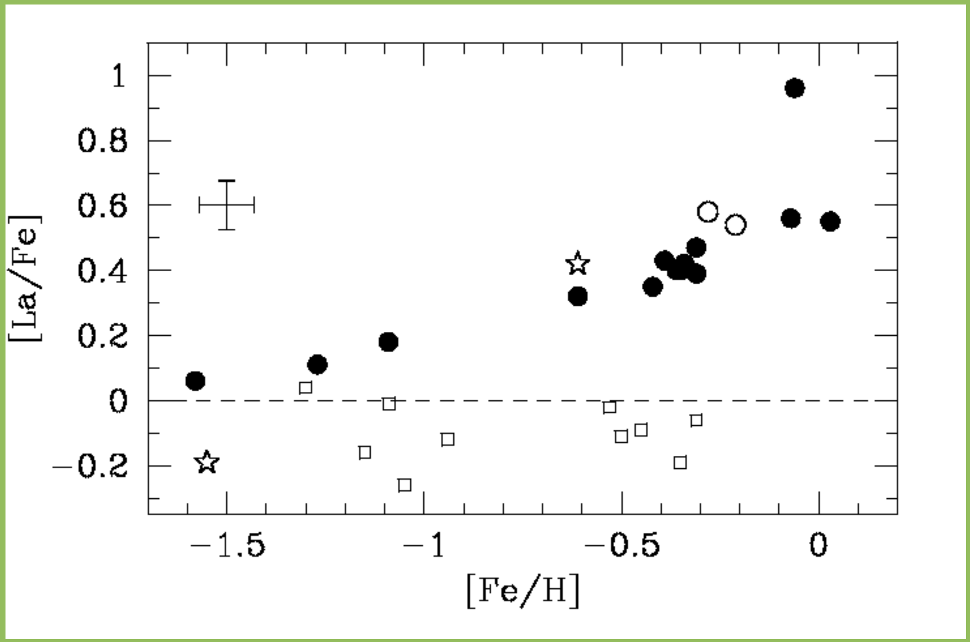
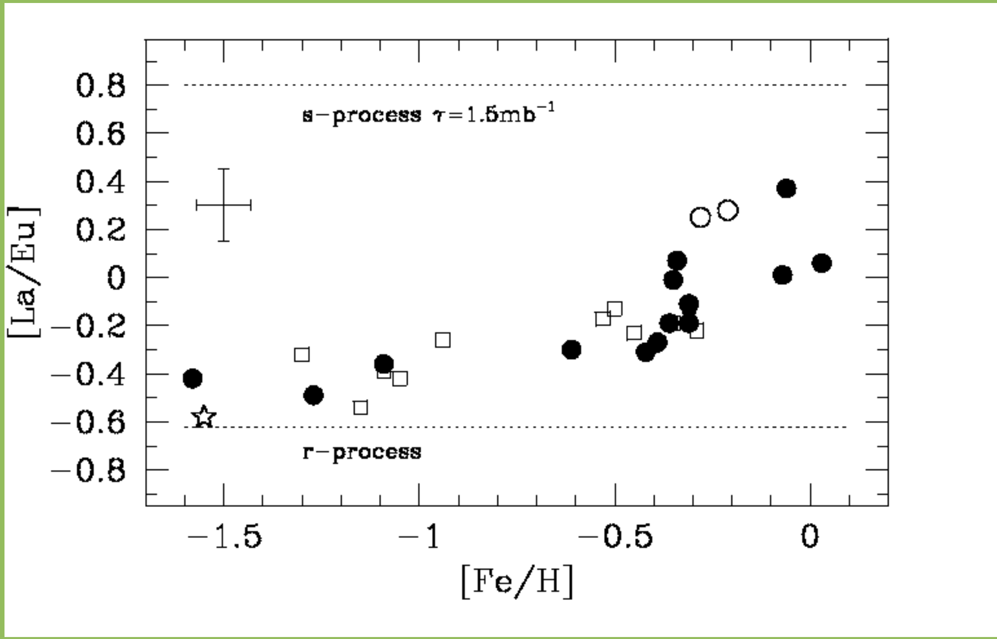
Neutron-capture elements in dwarf galaxies

Nearby dwarf galaxies show neutron-capture enhancements.

Sagittarius dSph Stars (with Smecker-Hane)



[La/Eu] toward the s-process ratio

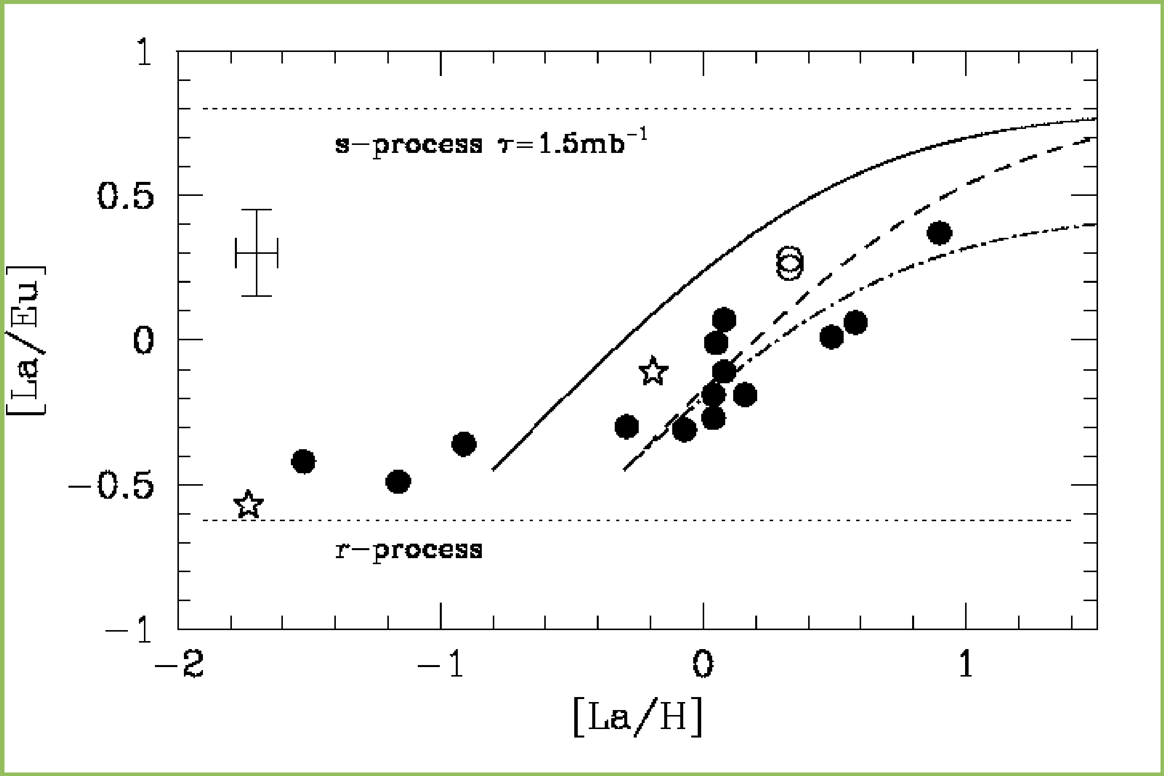


Fe commonly used as metallicity indicator.

Difficulties for modelling...

Solar system r-process

Dilution curves – remove Fe from the problem



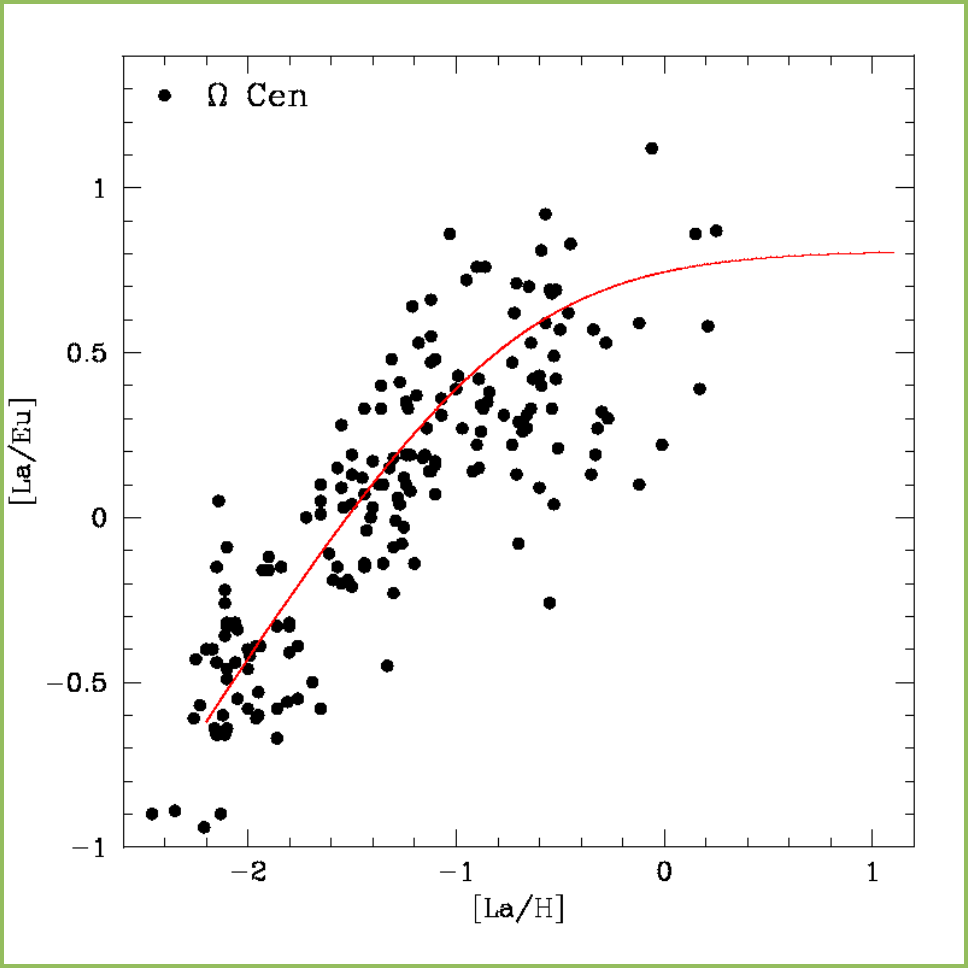
Solar system r-process

Solid and dashed lines show the locus of pure s-process added to a starting composition
The dot-dashed line shows 95% s-process plus 5% r-process.

Can't get a much simpler theory than this!

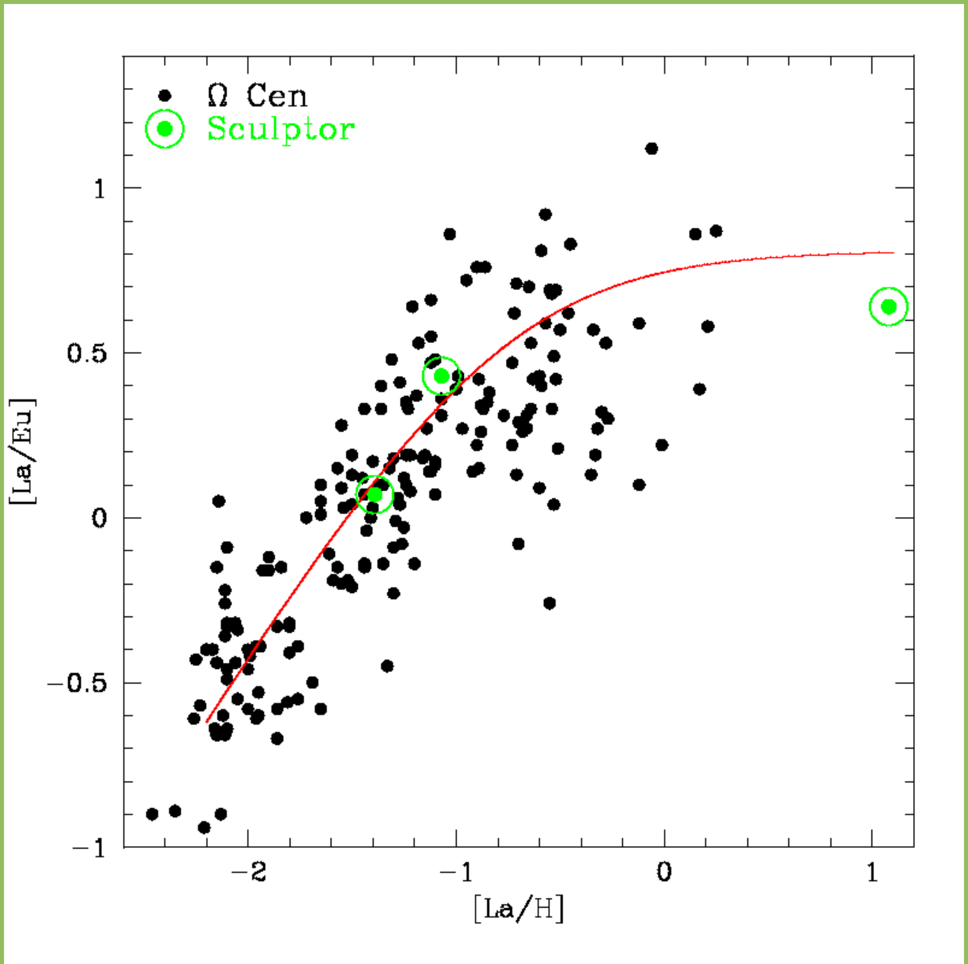
Sgr dSph started close to pure r-process composition, then at [La/H]~-0.4 added pure s-process

Johnson et al. (2010) Omega Cen data



Johnson et al. (2010) Omega Cen data

Dilution curve fixed at -2.2,-0.6



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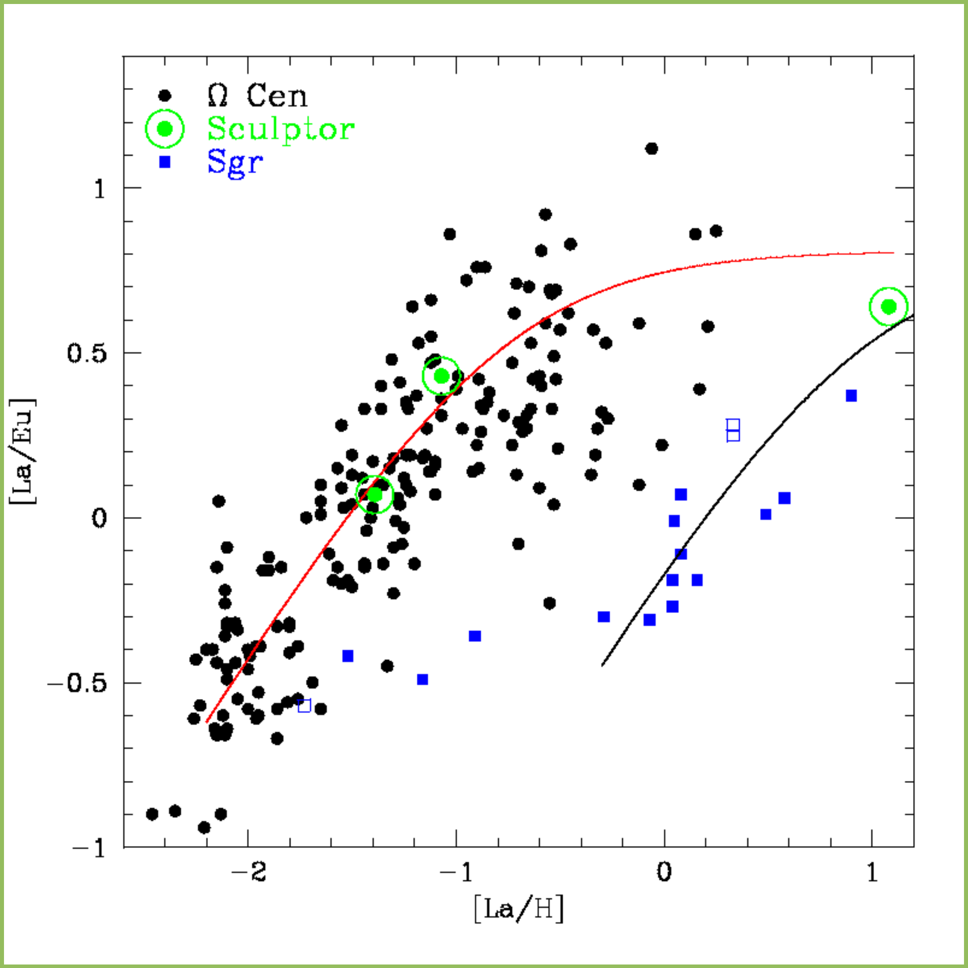
Geisler et al. (2005) Sculptor dSph



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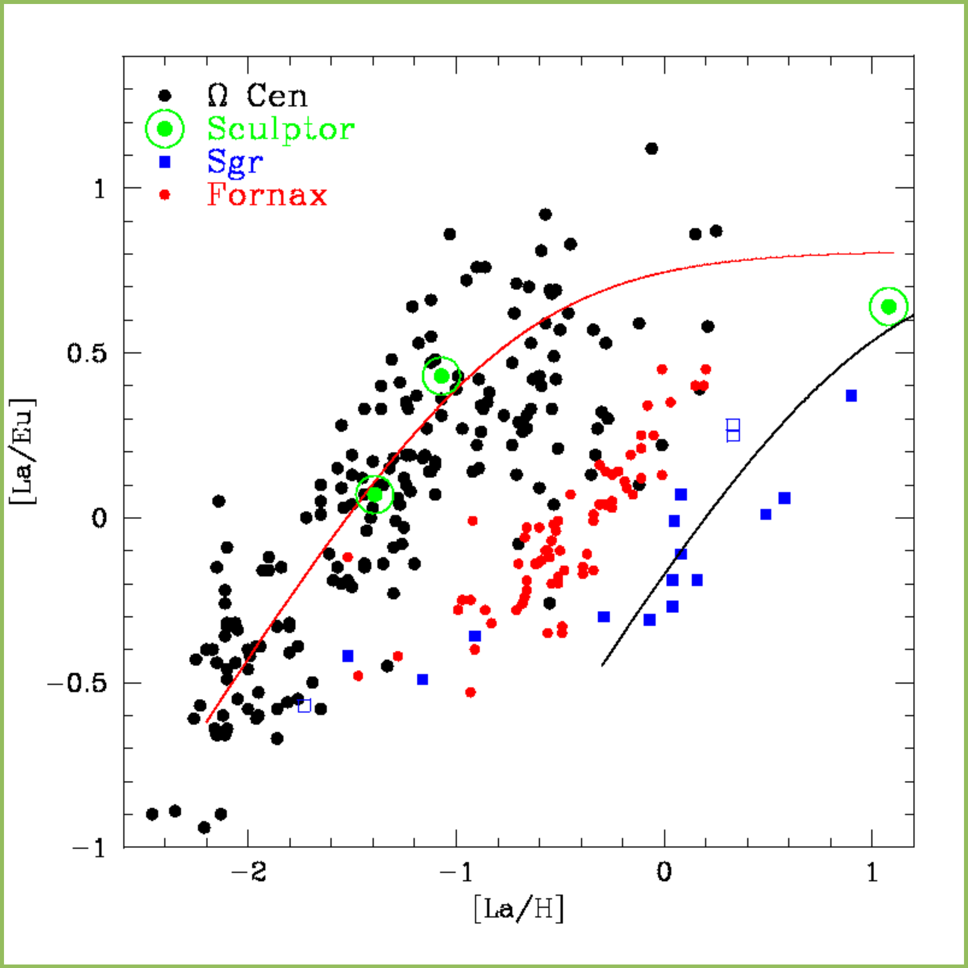
AMcW/TSH (2005) Sgr dSph
(notice lower envelope)



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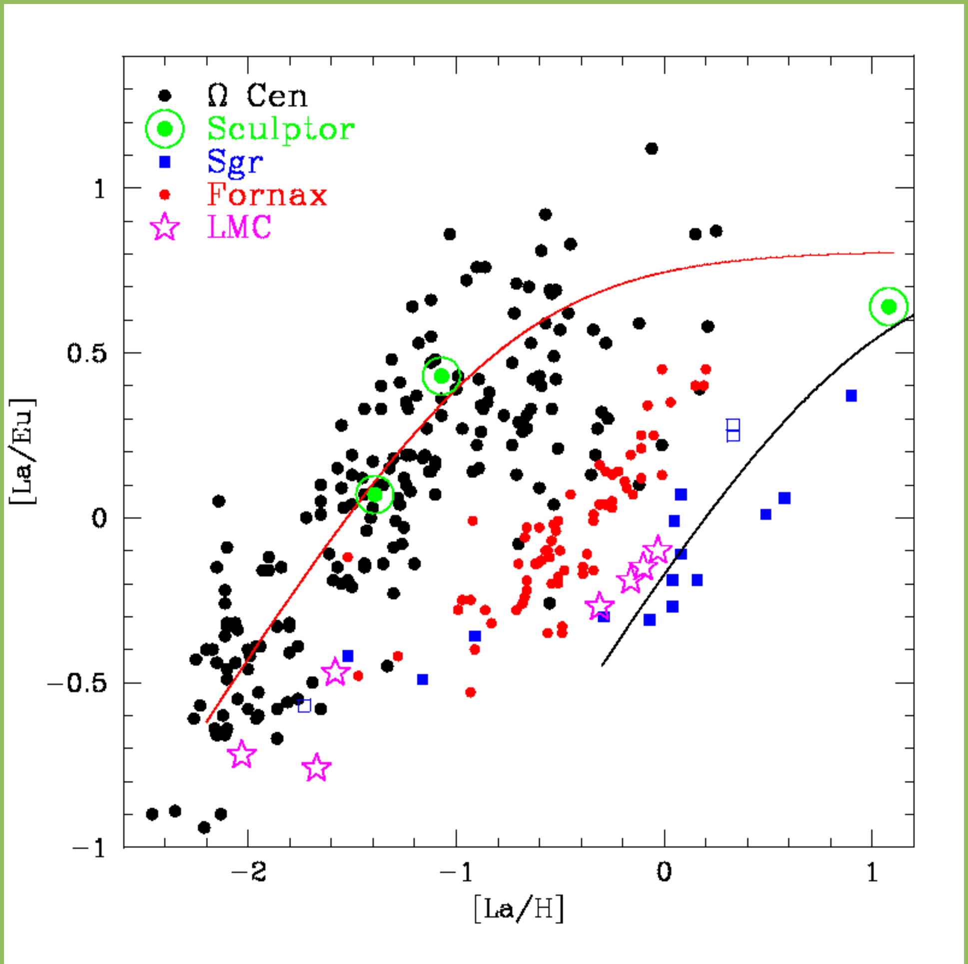
Letarte et al. (2010) Fornax dSph
(lower envelope?)



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Mucciarelli et al. LMC GCs
(two epochs of SF)

Some conclusions:

1. At least five dwarf galaxies show an early r-process dominated phase, followed by a pure s-process phase. Leaky Box chemical evolution...
2. Possible signature of weak s-processing from massive stars present (lower envelope).
3. Can identify the end of the r-process dominated phase with 1 point.
4. Useful for tracing late-time accreted dSphs in the Galaxy.